Hinging Around or Fixing It

Designer's Daily Delicate Decision

Idealistic Assumptions of Realistic Designers

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1. **Super Classic Topic to Talk About**

As soon as one start a topic about support type, almost all the engineering student completing basic analysis course and designers feel very familiar with "Hinge" or "Fixed" or "Roller" (shortly F/H/R) and a very classical topic to talk about. At the concept level, it is not difficult to understand how they are defined (they appear very innocent). During university life, they rarely bother the students as the problems that we deal are "Idealized" already or allowed to idealize. We wait till we leave the university wishing that the things will be more clear outside. But as soon as one starts analyzing, one of the simplest structures (cantilever beam, simply supported beam) manually or by computer, he has to "judge" and apply one of the above F/H/R support. What might the level and source of confidence here? What the novice analyst might do then? He may "Hinge Around" the idealistic and realistic judgments.

2. **Looking for Knowledge Source on F/H/R**

With a desire to build a confidence on 'selecting an appropriate support condition", one might think of various options. As we all know, the obvious ones are:

- Discuss with senior in the office
- Book on analysis
- Get appointment with professor
- Software technical reference
- So on

Based on our personal experience, little "direct" help can be obtained from the existing literature because as mentioned earlier, most of sources try to explain F/H/R in terms of "Translation and Rotation" and rarely in terms of the practical situations (drawing based). As the issue appears very simple in principle, we might afraid of "Over-simplifications". Things seem quite controversial here that why we find difficulty in handling simple matter? Is it worth exploring further?

3. **Some Sources of Confusion**

Some of the reasons that seem to complicate the simple issue are the following expressions and practice:

- Literature claiming that "No joint is truly F/HR"
- Analyzing the truss as "Hinged" framework but welding or bolting at the ends
- Assume the truss support as hinge or roller but we rarely "Device" a mechanical hinge or roller
- Geo-Tech engineer assuming structure as rigid body and structural engineer assuming soil to be rigid too
- Analyzing the column base plates as fixed or hinge without considering the plate stiffness, number/size/location of bolts etc.
- Single or multiple pile cap though rigid itself modeled as hinge

4. **Key Considerations and Clarifications**

The following points will be helpful to develop the overall idea about the issue;

a. One of the most important point regarding the choice of support is "Relative Bending Stiffnesses" of the members meeting at one joint.

   For a given identical detailing (weld, bolt, reinforcement, embedment), a relatively smaller member connected to other big member(s) can be considered "Closer to Hinge" because of its low stiffness compared to others. Less relative stiffness means, it participates less in bending.

   The higher "Clamping" or "Holding" capacity of bigger member, make other member "clamped" or "close to fix support" situation.

b. In general and for completeness, the support condition must be considered for a given member, one end and one direction at a time. In extreme scenario, one member can be four different support conditions (2 ends x 2 directions).

   We often hear people saying that "a member is Hinged" meaning both the ends and both the directions which may not be the real situation.

c. The support or connection condition can be viewed as the influence on bending behavior of other members on the member under consideration.

   One simple way to explain this is that a strong member can "Delay" the start of the bending on other smaller member (concept of disturbed and regular zone). In other words, the "Net" bending length of the smaller member will be shorter than its actual length.

d. The decision about support condition is more important to "Axial Compression" and "Beam" type members rather than tension members.

e. The support condition can be "Determined" in advance based ONLY upon the information about number of bolts, weld size, layout, anchorage, footing size, pile diameter, etc.

   The reason is similar to point (a) above. The decision can't be taken independently without knowing the other members meeting at the point. Simple analogue can be the grading of students in a class. We can't declare one student as the "Highest" or "Lowest" without knowing the score of all others.

f. The structural form (Truss, Frame or Panel) has great influence on sensitivity of the F/H/R decision.

   The choice of F/H at the ends of a truss member has practically negligible effects on the overall load transfer mechanism (distribution) because the form of the truss (triagularized) is such that the primary load path will be "tension –compression" and not bending (unless a heavy concentrated load is acting at the span point of a member). This topic is very interesting , practically useful and will be elaborated later.

g. Though sound basic, the realization that the moment capacity of member (section) or a system (frame, pile-caps) come from "Couple-Effects".

   This point can be utilized to explain many situations where the individual members may be weak in bending but they acting together can provide a moment resisting system. Simple case is the two pile cap.

h. Cumulative Compressive Force can give "Clamping" effects.

   One of the examples where this situation is found is the pre-cast construction where a thin precast large panel (typically 3 x 4 x .1m) is between load bearing walls just below and above it. The measured deflection clearly indicates the clamping effect of vertical load acting along the edge.

5. **Can We Check F/H/R by Analysis?**

Asking this question to engineers many of them feel (especially the computer-biased ones) that "Why not?" and answer forwarded is that

> *"Just create a simple two-column portal frame, apply hinge one side column and fixed on the other side column and run it, run the model and check that the moment on the hinge support is zero and other side will have some. This is how we verify the support by analysis!"*

The general answer that 'Can we check the F/H/R by Analysis?" is that "Yes" on the basis of "Sub-structure modeling or micro-modeling". Let's take some examples:

Pile with Cap foundation:

If we create a model of the cap, pile, soil media (as solid or spring elements) and analyze only that part (without super-structure), it is possible to predict the "Stiffness" or inversely "The Flexibility" of the sub-system at the point that connects the super-structure. One vertical, horizontal and moment load at the top of the system and corresponding deflections (& rotations) can be used to compute the stiffness. This will tell us quantitatively the stiffness of the foundation assembly. Then comparing the stiffness with the super-structure member that connects that foundation can be evaluated as "Closer" to F/H.

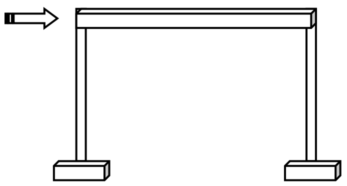
Column Base Plate:

Similar to Pile-Cap sub-system, the micro-model including the actual dimension of the plate, size and layout of bolts, concrete medium and part of the column. Unit loads and moment applied along each direction of interest, analyzing the model, getting the corresponding deflection (rotation), computing stiffness (or flexibility) can lead to the quantitative assessment of the system. Comparing these values with corresponding stiffness (Mx,cap etc) of the column will give us the relative stiffness.

Many other examples like this can be quoted. Having discussed the above assessment of joint stiffness it's very logical to expect a question like "It is worth doing all these or it is affordable to do so in daily design?".We understand very well that adopting such procedure only the regular design is not practical or affordable but to develop the skill, understanding the behavior of such joint, it is worth spending some time on this if our main profession is the "Structural Design".

6. **Can We Check F/H/R by Test?**

Keeping aside the cost of test set-up etc for a while, it is possible to test the "Stiffness Behavior" of most of the structural joints (sub-systems) in lab or at site. Lets take a simple example that we would like to know the "Fixing" level of the base supports:



For this simple portal frame (RC or Steel), set-up the foundation system (under investigation), portal frame, simple loading frame + device (not shown), way to measure the horizontal deflection of the frame. Just by recording the horizontal push (by jacks) and measuring the displacement, we can plot the load-deflection curve.

With the same dimensions, we can create two models in computers: Simply supported at base and fixed at the base. We apply some load (better similar to that applied at test), analyze the frame and note the lateral deflection for a given load value for fix and hinge base cases.

With the information from test and by computation, we can compare the horizontal displacement values and have a feeling about the "Closeness" of the foundation system with Fixed or Hinged.

There are several full scale test results available in the literature which can be used to develop the understanding without investing or re-inventing the wheel.

7. **Practical Situations (Typical)**

Single Pile Cap

Two Pile Cap
Three Pile Cap

Column Base-plate with Two Bolts
Column Base-plate with Four Bolts

Truss Members
Truss Ends

8. **What is the "Seriousness of Wrong Assumption"**

As mentioned earlier, the sensitivity of this selection depends upon many factors. Perhaps the most important one is the "Primary Load Transfer Mechanism or the Framing System". The author was once involved in the investigation of failure of a industrial structure in Southern Thailand (Surat Thani) in which after detailed investigation (Macro – Micro analysis) it was found that the failure of the entire roof of a large factory was due to a simple "Engineering Judgment Error". The problem at hear was that the roof truss which was supported on two more than 6m high I-shaped steel column was analyzed as Hinged supported on one side (left column) and Roller at the other side. The detailing adopted at the site was on both the sides, the top of the column (with plate) was welded with the truss. The column received excessive horizontal thrust from the truss, diverted and finally failed due to P-Delta effects which was not considered in the design (designed for vertical load and small wind load).

It is difficult to provide a generalized answer to this question but even if the consequence many not as serious as the above incident, for many structure (least the truss members), the assumption has direct impact on member size, detailing, cost, deflection, serviceability, etc. One of the major concern is the place of reinforcement on wrong side (compression side) based on the results of the analysis with or without-moment support condition.

9. **General Recommendations**

Careful study of the full scale test results, long-column design principles (especially the K-factor charts or equations), stiffness differences due to boundary conditions (a beam with both side fixes, hinge or one end cantilever), analysis of joints with mixed member sizes (all small, small-medium-big, big-big), etc can be considered as the sources in developing the knowledge in this "Simple Looking" area of analysis.

10. **Conclusion**

Even after discussion some controversies, ways to assess the joint fixing, typical practical scenarios, we can't undermine the importance point that "Central to Any Engineering Decision is the Exercise of Judgment" and proper analysis, experience, studies can contribute to our judgment.

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